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MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2022/2023

ENT4046 – N/MEMS
(NE)

3 JULY 2023
09:00 a.m. - 11:00 a.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 4 pages with **4 Questions** only.
2. Attempt **ALL FOUR** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.
4. The List of Constants, List of Formulas, and Appendix are given in Page 4.

QUESTION 1

- (a) Explain what *microelectromechanical system* (MEMS) is. [5 marks]
- (b) List the **SIX(6)** energy domains in MEMS and give **TWO(2)** parameters for each of the energy domains. [6 marks]
- (c) Sketch the block diagrams of different transduction effects: (i) *self-generating transduction without parasitic*, (ii) *self-generating transduction with parasitic*, (iii) *modulating transduction without parasitic*, and (iv) *modulating transduction with parasitic*, respectively. Explain the diagrams by giving **ONE(1)** example for each of the effects. [6+8 marks]

QUESTION 2

- (a) A rectangular silicon (Si) diaphragm has plate dimensions of length=486 μm , width=270 μm and thickness=5 μm . Given that the diaphragm is subjected to a pressure of 8 MPa and it has a Young's modulus of 190 GPa, calculate the *maximum stress* and *deflection* in the diaphragm, respectively. [8 marks]
- (b) Sketch the plot of creep deformation of materials at elevated temperature, *strain* as a function with *time*, and discuss the thermal effects on creep deformation. [3+4 marks]
- (c) (i) Using suitable diagrams, illustrate *laminar flow* and *turbulent flow*, respectively. [3 marks]
(ii) Distinguish laminar flow and turbulent flow in the contexts of *Reynold number*, *flow patterns*, and *velocity profile*, respectively. [7 marks]

QUESTION 3

- (a) **Figure Q3(a)** shows a comb-drive lateral actuator with 6 moveable fingers, the thickness of the fingers and the gap, g , between the fingers are 3 μm , respectively; the medium between the fingers is air; the stiffness of the tethers holding the moveable comb is 0.02 N/m. Answer the following:
- (i) Calculate the total lateral electrostatic force if the applied actuation voltage is 25 V. [4 marks]
- (ii) Calculate the deflection of the comb. [2 marks]
- (iii) Comment on strengths of using comb-drive structure with lateral deflection in MEMS design. [3 marks]

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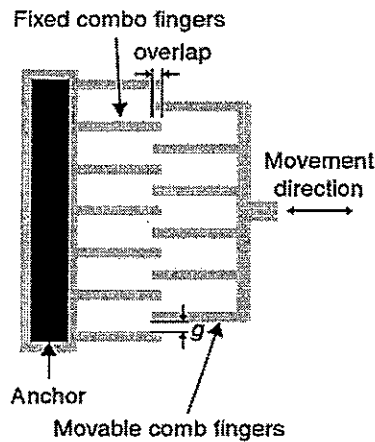


Figure Q3(a)

- (b) (i) With the aid of a Wheatstone bridge circuit and derivation, explain how the circuit works in measuring small changes in resistance. [6+4=10 marks]
- (ii) With justifications, compare in a table the Wheatstone bridges: quarter-bridge, half-bridge (Type I, diagonal-bridge), half-bridge (Type II), and full-bridge, in the contexts of *linearity error*, *temperature compensation* and *sensitivity*, respectively. [0.5×12=6 marks]

QUESTION 4

- (a) Given the electrostatic potential energy of parallel-plate electrodes is: $U = -\frac{1}{2}CV^2$ where C is the capacitance and V is the applied voltage, and the applied voltage is proportional to the gap between the parallel plates, $V \propto d$. Answer the following:
- (i) Express the scaling of the electrostatic potential energy (U) and the electrostatic forces (F_d , F_w and F_L), in the form of linear dimensions, respectively. [7 marks]
- (ii) Find the reductions in the electrostatic potential energy and the electrostatic forces if the linear dimensions are reduced by a factor of 100. [3 marks]
- (b) With aid of diagrams, design the step-by-step process to fabricate the piezoelectric accelerometer with a proof mass shown in Figure Q4(b) begins from a bare silicon wafer. Label clearly the diagrams.

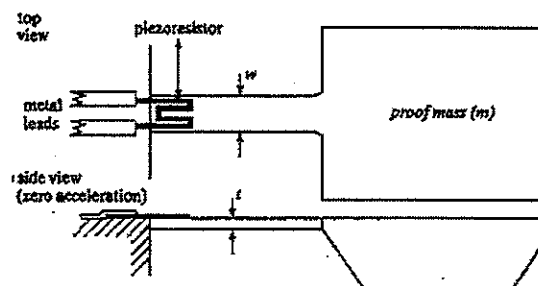


Figure Q4(b)

[15 marks]
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LIST OF CONSTANTS

Electron mass in free space, $m_o = 9.11 \times 10^{-31}$ kg

Planck's constant, $h = 6.63 \times 10^{-34}$ Js

Electronic charge, $e = 1.60 \times 10^{-19}$ C

Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK⁻¹

Speed of light, $c = 3 \times 10^8$ ms⁻¹

Permittivity of free space, $\epsilon_o = 8.85 \times 10^{-14}$ Fcm⁻¹

Temperature in Kelvin, $T(K) = T(^{\circ}C) + 273$ K

LIST OF FORMULAS

$w_{\max} = -\frac{0.0138pa^4}{Eh^3}$	$\sigma_{\max} = \frac{0.308pa^2}{h^2}$
$w_{\max} = -\alpha \frac{pb^4}{Eh^3}$	$(\sigma_{yy})_{\max} = \beta \frac{pb^2}{h^2}$
$w_{\max} = -\frac{3W(m^2 - 1)a^2}{16\pi Em^2 h^3}$	$(\sigma_{rr})_{\max} = \frac{3W}{4\pi h^2}$
$\delta = \frac{FL^3}{3EI}$	$c = 16f\left(\frac{W}{L}\right)W^3 LH_o^3$
$k = \frac{F}{\delta} = \frac{3EI}{L^3}$	$c = \frac{2\mu Lb}{H}$
$I = \frac{bh^3}{12}$	$\rho = \frac{2h}{3(\alpha_2 - \alpha_1)T}$
$F = \frac{(\alpha_2 - \alpha_1)T}{8} \frac{hb}{\left(\frac{1}{E_1} + \frac{1}{E_2}\right)}$	$\frac{\theta}{\text{arc}(AC)} \approx \frac{\theta}{\text{line}(AC)} = \frac{360}{2\pi\rho}$
$\Delta P = Q\left(\frac{8\mu L}{\pi r^4}\right)$	$\delta = \rho - \rho \cos \theta$
$\Delta P = Q\left(\frac{12\mu L}{wd^3}\right)$	$C = \frac{\epsilon_r \epsilon_o A}{d}$
$F_d = -\frac{\epsilon_r \epsilon_o WL V^2}{2d^2}$	$F_W = \frac{\epsilon_r \epsilon_o LV^2}{2d}$ or $F_L = \frac{\epsilon_r \epsilon_o WV^2}{2d}$
$k = N\left(\frac{12EI}{L^3}\right)$	$U_P = \sqrt{\frac{8}{27} \frac{kd^3}{\epsilon_o A}}$

APPENDIX

Table of Coefficients for Maximum Stress and Deflection in a Rectangular Plate.

a/b	1	1.2	1.4	1.6	1.8	2.0	∞
α	0.0138	0.0188	0.0226	0.0251	0.0267	0.0277	0.0284
β	0.3078	0.3834	0.4356	0.4680	0.4872	0.4974	0.5000

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